3.5.1 Newton's laws of motion

	Learning outcomes	Additional guidance
	Learners should be able to demonstrate and apply their knowledge and understanding of:	
(a)	Newton's three laws of motion	HSW7
(b)	linear momentum; $p = mv$; vector nature of momentum	
(c)	net force = rate of change of momentum; $F = \frac{\Delta p}{\Delta t}$	Learners are expected to know that $F = ma$ is a special case of this equation. HSW9, 10 *M2.1, M3.9*
(d)	impulse of a force; impulse = $F\Delta t$	
(e)	impulse is equal to the area under a force–time graph.	Learners will also be expected to estimate the area under non-linear graphs. HSW3 Using a spreadsheet to determine impulse from *F–t* graph. *M3.8, M4.3*

3.5.2 Collisions

	Learning outcomes	Additional guidance
	Learners should be able to demonstrate and apply their knowledge and understanding of:	
(a)	the principle of conservation of momentum	HSW7
(b)	collisions and interaction of bodies in one dimension and in two dimensions	Two-dimensional problems will only be assessed at A level. HSW11, 12
(c)	perfectly elastic collision and inelastic collision.	HSW1, 2, 6

(6) M - Define and calculate linear momentum
(7) S - Define elastic and inelastic collisions and decide if a collision is either.
(8) C - Apply the principle of conservation of linear momentum to complex problems.

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Lesson 2 . Linear Momentum

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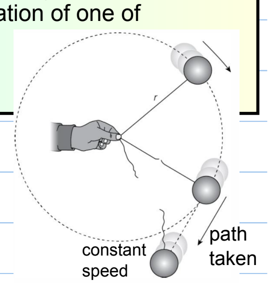
A

STARTER: Explain how whirling a ball on a string in a circular path **and then** cutting the string is an illustration of one of Newton's laws.

Consider forces / resultant force



- **1st law.**
- Before string in cut, the velocity is changing - therefore a resultant force must be acting.
- This resultant force is provided from the centripetal / tension force from the string acting towards the hand.
- When the string is cut, this force is removed so the **resultant force** is zero.
- Ball moves off with a constant velocity

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Momentum

Key point

Linear momentum is defined by the equation:

gun - discuss system

Momentum = mass x velocity

$$p = m v$$

The law of conservation of momentum:

For a system of interacting objects, the **total momentum** in a specific direction is **constant,** as long as no external forces act on the system

(Total momentum before and after an interaction is the same (in a single direction))

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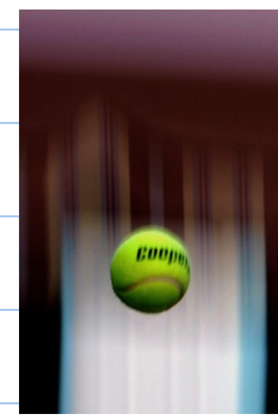
A massive ball is released from rest above the ground. According to a student, the principle of conservation of momentum is violated because the ball gains momentum as it falls.

Explain why the student's observation is incomplete and discuss how momentum is conserved in this situation.



Answer: Earth mentioned (as an integral part of the system)

The Earth has (equal and) opposite momentum to the (falling) ball (so momentum is conserved)
or
The Earth moves upwards / towards the ball (with a tiny speed, so momentum is conserved)

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Example

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A railway carriage of 5.00×10^4 kg moves along a track at 2.50 m s^{-1}. It collides with a second, stationary, carriage with a mass of 4.00×10^4 kg and the carriages join together.

a Calculate the initial velocity of the coupled carriages after the impact. (*2 marks*)

b Calculate the change in kinetic energy during the collision and hence determine if the collision is elastic or inelastic. (*4 marks*)

$m_a = 5\times10^4$, $v_a = 2.5$ $\quad$ $m_b = 4\times10^4$, $v_b = 0$

① $\boxed{a}$ $\quad$ $\boxed{b}$

$P_T = m_a v_a + m_b v_b = 5\times10^4 \times 2.5$

$= 125\,000$ kgms^{-1}

② $v_{ab} = ?$

P_T = Same. $m_{ab} = 9\times10^4$

$V = \frac{P_T}{m_{ab}} = 1.39$ ms^{-1}

$KE_{before} = \frac{1}{2} m_a v_a^2 = \_\_\_\_ J$ ghgfd

$KE_{after} = \frac{1}{2} m_{ab} v_{ab}^2 = \_\_\_\_ J$

fg

fg

g

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ACTIVITY 1: Define elastic and inelastic collisions.

demo

Complete the table below.

Collision type	Momentum	Kinetic energy	Total energy

Kilo 10^3

Mega 10^6

Giga 10^9

Key point

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ACTIVITY 1: Complete the linear momentum worksheet. Show your full working out.

HWK:

Kilo 10^3 **Support** - How does this activity link to the space topic

Mega 10^6 **Ex 1** - Exercise 7.6 (Lowe)

Giga 10^9

Questions

1 Two snooker balls, A and B, with the same mass move towards each other and collide. The initial velocity for A is $+0.3\text{ m s}^{-1}$, and for B is -0.2 m s^{-1}. The final velocity of A is -0.2 m s^{-1}.

a Determine the final velocity of B. *(1 mark)*

b Show whether the collision is elastic. *(2 marks)*

2 A mass of 5.00 kg moving with velocity 20.0 m s^{-1} to the right collides with a stationary mass of 10.0 kg. The final velocity of the 5.00 kg mass is 6.67 m s^{-1} to the left.

a Calculate the final velocity of the 10.0 kg mass. *(2 marks)*

b Is the collision elastic? *(2 marks)*

3 A 1.0 kg mass with initial velocity 5.0 m s^{-1} collides with, and sticks to, a stationary 6.0 kg mass. The combined mass collides with, and sticks to, a stationary 3.0 kg mass. The collisions are all head-on.

Calculate:

a the final velocity *(2 marks)*

b the kinetic energy lost. *(3 marks)*

4 An alpha particle of mass 4.0 u with a velocity of $1.0 \times 10^6\text{ m s}^{-1}$ to the right collides with a stationary proton of mass 1.0 u. After the collision, the alpha particle moves with velocity $0.60 \times 10^6\text{ m s}^{-1}$ to the right.

a Calculate the velocity of the proton. *(2 marks)*

b Show that the collision is elastic. *(3 marks)*

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23 When a gardener aims water from a hosepipe at the ground, he notices that the water always splashes in many directions. Fig. 22.1 shows the splashes produced by a vertical jet of water hitting the ground.

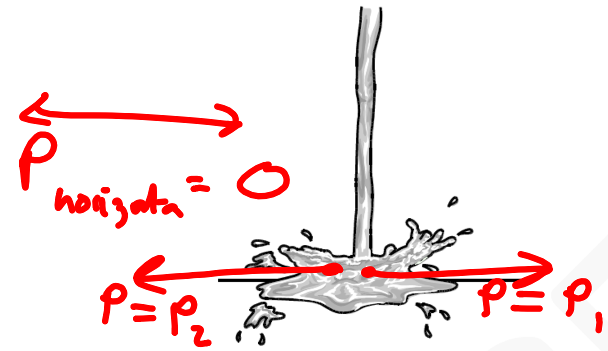

Fig. 22.1

(a) Using ideas about momentum explain why the water splashes in many directions.

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Mini plenary

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Exercise 7.6: Examination questions

1 A bullet of mass 15 g is fired horizontally from a gun with a velocity of $250\,\mathrm{m\,s^{-1}}$. It hits, and becomes embedded in, a block of wood of mass 3000 g which is freely suspended by long strings, as shown in Fig. 7.7. Air resistance is to be neglected.

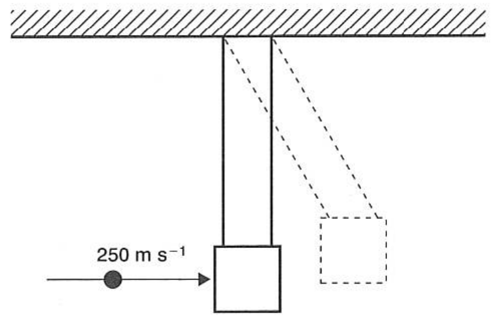

Fig. 7.7

(i) Calculate the magnitude of the momentum of the bullet as it leaves the gun.

(ii) Calculate the magnitude of the initial velocity of the wooden block and bullet after impact.

(iii) Use your answer to (ii) to calculate the kinetic energy of the wooden block and embedded bullet immediately after the impact.

(iv) Hence calculate the maximum height above the equilibrium position to which the wooden block, with the embedded bullet, rises after impact (assume $g = 10\,\mathrm{m\,s^{-2}}$).

[CCEA 2000, part]